FACTORS INFLUENCING HEAT STRESS IN FEEDLOT CATTLE AND METHODS OF HEAT STRESS ALLEVIATION IN FEEDLOT CATTLE AND BROILER CHICKS

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INTRODUCTION

Fluctuation in cattle prices and high costs of production reduce the profit margin for cattle feeders. Large numbers of cattle are fed in arid regions of the U.S. where mean daytime temperatures often exceed 37 C. Heat stress can diminish the profit margin in cattle feeding by decreasing cattle performance. Although shades or sprinkling systems have been effective in reducing heat stress in some parts of the U.S., more studies are needed to determine where the practice will be economically useful. Dietary modifications also may reduce heat stress either through a reduced heat increment of the diet or by counteracting metabolic changes that occur as a result of heat stress.

Confinement systems for finishing cattle have been of interest recently. Some researchers have indicated that confinement facilities reduce cattle performance compared with conventional dirt-lot feedlot pens. Further experiments are needed to determine the optimum cattle density, amounts of feed bunk and watering space and environmental modifications for maximum performance for cattle in expensive confinement facilities. Type of breeding (Bos indicus versus Bos taurus type), acclimatation, and hair coat color and density also may determine which animals will adapt best to a given environment. Feeding behavior of feedlot cattle also can be altered by environmental conditions and should be considered together with other management practices. Further investigation of these topics should be of practical value to many cattle producers and may increase the efficiency of cattle production in hotter climates of the world.

CHAPTER II

REVIEW OF LITERATURE

Heat stress of feedlot cattle in the southern Great Plains can cause substantial economic losses to cattle feeders. Losses due both to death of animals and to decreased performance can determine whether a cattle feeder will make or lose money on a pen of cattle. The decrease in average daily gain and feed conversion efficiency associated with heat stress of cattle appears to result primarily from decreased feed consumption. For cattle on full feed, heat stress can reduce feed intake by 10-35 percent (NRC, 1981). Olbrich et al. (1973) indicated that ambient temperature had no influence on digestibility and that digestibilities were similar for both heat and cold tolerant feedlot cattle. Kelly et al. (1967) however, demonstrated that even when feed intake was maintained, an increase in ambient temperature increased the molar percentage of acetate and decreased the molar percentage of propionate in the rumen. Based on the efficiency of production and, possibly, metabolism of these two acids, this change decreases the efficiency of feed utilization. Other workers have shown that longer term exposure to a high ambient temperature (38 C for five days) independent of feed intake, reduced ruminal motility and total VFA's (Attebery and Johnson, 1969). In contrast, one or two days at 35 C caused no significant change in either rumen motility or the volatile fatty acid (VFA) profile. Whether temperature or time was more important in altering rumen function is not clear from this trial. Exposure to 38 C elevated ($P<.05$) rectal temperature to 40.9 C. This elevation was suggested to be responsible for the reduction in amplitude of rumen contractions. In contrast, conclusions by the NRC (1981) indicate that when ambient temperature increases above the thermoneutral zone, digestibility will increase, due primarily to a greater retention time of feed in the gastrointestinal tract. Most studies cited by the NRC were for cattle consuming higher roughage diets. Heat stress of sheep did not increase digestibility of concentrate diets (NRC, 1981). If feed intake declines, an increase in digestibility of less well processed feedlot diets and roughage diets would be expected, though this change should be less than 4% per multiple of maintenance change in feed intake (NRC, 1981). Further study of the influence of heat and cold stress on digestibility and rate of passage is needed.

Both acute and chronic heat stress affect the maintenance energy requirement of livestock (NRC, 1981). First, with prolonged exposure to heat, animals acclimate and certain hormonal and metabolic changes occur within the animal. Chronic changes are associated with seasons both with and without weather fluctuation. Daily weather fluctuations can cause acute heat stress. The NRC (1981) suggested that the energy requirement for maintenance will change with either acute or chronic heat stress by the following equation:

$$NE_m = aW^{.75}$$

where NE_m = net energy for maintenance (Mcal/day)

a = 0.077 for the thermoneutral zone

W = live weight (kg)

For each degree C prior exposure to ambient temperatures above or below 20 C, 0.0007 should be subtracted or added respectively to "a" in the equation. This means that at 35 C, the energy required for maintenance is 14% greater than at 20 C. With acute heat stress, the type and intensity of panting can provide an index of the increased energy need for maintenance. When panting is in the first phase (rapid and shallow), the maintenance energy requirement will increase by 7 percent. If cattle are experiencing second phase breathing (open mouth with slower, deeper breaths) the maintenance energy requirement is increased from 11-25 percent. Severe heat stress increases the maintenance requirements by increasing the energy costs of panting and altering tissue metabolism (NRC, 1981). The magnitude of these adjustments needs further testing under feedlot conditions.

Much of the research with heat stress has been conducted in environmental chambers. Though chambers help control and create reproducible environmental conditions, they usually cannot duplicate conditions which cattle encounter in a typical feedlot environment with continual fluctuations in temperature, wind, sunlight intensity and humidity. In addition to heat from convection and a slight amount from conduction, cattle in feedlots typically receive additional heat from radiation. Further, feed intakes generally are higher for feedlot than chambered cattle, so the heat load both from the heat of fermentation and from heat of metabolism may be greater with steers in a feedlot. Compared with chambered cattle, feedlot cattle may experience more heat stress due to high humidity. Greater wind movement in the outdoor environment, however, would aid in reducing this additional heat load by allowing increased heat loss through evaporative cooling. This is true, however, only if ambient air temperature is below the body temperature of the animal. If ambient air temperature is above body temperature, air movement would increase the animal's heat load by conduction. These factors should affect the temperature and time needed to produce heat stress. Conditions less extreme than 38 C for 5 days has caused death of feedlot cattle, so under practical conditions, requisites for heat stress of cattle in feedlots may be less extreme than those described by Attebery and Johnson (1969).

Some researchers have devised formulas considering the various weather factors into a heat stress index for cattle and other animals. Bianca (1962) determined the relative importance of dry and wet bulb temperatures in causing heat stress in cattle. Weighting of dry and wet bulb temperatures (15% and 85%), which correlates well with heat stress in humans (Provins et al. 1962), did not apply to heat stress of cattle. He found that a different weighting (35% dry bulb and 65% wet bulb) corresponded more closely to rectal temperature in cattle. This finding could reflect species differences in the capacity for evaporation. Man can dissipate about 190% of metabolic heat production by evaporation of moisture compared with only 105% for cattle of European breeds (Bianca, 1962). He also suggested that for man, evaporative heat loss is primarily from the skin, while for cattle, evaporative heat loss through the respiratory tract is more important. Humidity of the air affects evaporation from the respiratory tract less than it affects evaporation from the skin. This is because air in the respiratory tract is warm and has a higher vapor pressure at saturation than air in contact with skin.

Although the effects of ambient temperature and humidity on heat stress are widely discussed, additional variables dictate how much heat stress any particular animal can withstand. Lee (1965) has divided these variables into three sets:

1. Environmental variables

   temperature, humidity, air movement, radiant heat, precipitation.

2. Animal characteristics

   species, breed and type, metabolic state, coat, age and sex, acclimatation, nutrition and hydration, derangement and disease, individual variability.

3. Criteria of response

   productivity, growth, reproductivity, physiological responses, pathological patterns.

Lee indicated that it was impossible to develop a predictive scheme involving all of these variables. In Lee's equations, environmental factors are considered first. Next, a typical individual of stated physiological characteristics with variations in metabolic rate and coat is considered. This index can be used to compare the innate adaptability of animals with different but known metabolic rates, coat insulation, sweating capabilities, maximum respiratory volumes and surface areas. It can also be used to compare the relative effectiveness of different types of environmental controls in livestock housing. When records permit, index values can be used to predict economic return. However, this index does not successfully predict specific physiological reactions to environmental conditions since each physiological effect responds individually to heat stress.

Shades

The most common type of heat shelter for feedlot cattle is a shade constructed over a portion of the feedlot to protect cattle from radiant heat. Several studies have shown the benefits of shade, but their value depends on the region of the U.S. in which the study was conducted. Ittner et al. (1958) indicated that shading can reduce the radiant heat load by 50 percent. In another California study, cattle with shade gained .29 kg more per day and required .64 kg less feed per kg gain than cattle without shade (Garrett et al., 1960). Beneficial results from shade have also been shown in Arizona

(Chiles and Pahnish, 1952; Nelms and Roubicek, 1957), Florida (Peacock et al., 1965), Kansas (Boren et al., 1961) and Louisana (McDaniel and Roark, 1956; Pontiff et al., 1972). In contrast, studies from Georgia (McCormick et al., 1963) and Nebraska (Bond and Laster, 1975) showed no beneficial response to shade.

Response may vary with the height, design, and type of materials used in construction of a shade. A series of studies in California (Ittner et al., 1958) examined the influence of shade design and construction on heat stress in cattle. Roofing material consisting of a 100-150 mm layer of hay provided the coolest shade though it deteriorated quickly. Galvanized steel sheets and aluminum sheets provided satisfactory shade, especially if the top was painted white to reflect solar radiation and the bottom was painted black to reduce the reflection of radiation back to the cattle. They also noted that wood provided good shade, but cracks between the boards to aid air flow produced a hotter environment than a solid shade. Ittner et al., (1958) suggested that the optimum shade height was between 3.0 and 3.7 m. They also found that an East-West orientation reduced the radiant heat most. However, a North-South orientation promoted better sanitary conditions and is preferred by most cattlemen.

Garrett et al. (1967) used trials at two locations in California (Davis and El Centro) to examine the influence of shade height on physiological responses of cattle to heat stress. They found that heat stress decreased as shade height increased (from 1.83 m to 3.66

m) as measured by black globe temperature, surface temperature, rectal temperature and respiration rate.

Sprinkling

A common method to reduce heat stress of livestock is by sprinkling with water. As with shades, the results from sprinkling have varied with geographic location and climatic conditions and various characteristics of cattle as suggested by Lee (1968). Morrison et al. (1973) sprinkled cattle for one minute every 30 minutes during which ambient air temperature exceeded 27 C. Sprinkling increased feed intake and weight gain, but feed conversion efficiency was not affected. Though sprinkled cattle had slightly higher respiration rates and rectal temperatures than cattle kept in an air-conditioned barn maintained at 24 C, performance was comparable. These results were confirmed in a later experiment. Sprinkling for one minute every 60 minutes also improved performance but to a lesser degree (Lofgreen et al., 1973). However, sprinkling appeared to be detrimental when heat stress conditions lessened and cattle approached market weight. In a subsequent study, they found that sprinkling improved the performance of cattle started on feed between 230 and 320 kg but did not improve performance of heavier cattle (360 to 390 kg) which had been acclimated to the conditions for some time (Morrison et al., 1974).

In a Kansas study (Nichols et al., 1982), cattle were sprinkled for two minutes every half hour during which ambient air temperature exceeded 27 C. Sprinkled cattle gained 16 percent faster ($P<.05$) and made 14 percent more efficient use of feed than nonsprinkled cattle. Feed intakes were very similar. Sprinkling may not be the answer under all conditions, however. Ittner et al. (1958) proposed that when humidity is high, sprinkling becomes less effective. Sprinkling is superior for relieving heat stress to providing a fine mist or fogging. Foggers increase the humidity to a greater extent than sprinklers (Nichols et al., 1982). With sprinkling, lots may become muddy and mobility of cattle may be reduced which will depress animal performance.

Adaptation

Acclimatation to a hot environment also plays a role in susceptibility to heat stress. Bianca (1959a) studied acclimatation to a hot dry environment using three Ayrshire bull calves. For 21 successive days, calves were exposed to a 45 C dry bulb and 28 C wet bulb temperature for up to 5 h each day in a climatic room. During the first exposure to heat, rectal temperature increased a mean of 2.2 C (from 39.6 to 41.8 C). However, over the 21 day period, mostly during the first half, signs of heat stress--rectal temperature, heart rate, respiratory rate and labored breathing--gradually subsided. During the last heat exposure, rectal temperature still increased by 2.6 C (38.5 to 41.1 C). Much of the improvement appeared to be due to a lower initial rectal temperature rather than a change in increment.

Another study by Bianca (1959b) examined the acclimatation of three calves to a hot humid environment. Dry bulb temperature in the climatic chamber was 40 C and wet bulb temperature was 38 C. Animals were exposed for up to 110 minutes each day for one to two weeks. Progressive changes included a decreased response in rectal and skin temperature to the heat. Tolerance time which the cattle could withstand the hot environment before reaching a rectal temperature of 42 C increased. With adaptation, respiratory rate rose faster and to higher levels at a given body temperature while heart rate decreased markedly. Based on these experiments, Bianca concluded that adaptation was due to a decrease in the metabolic heat production.

From a review by Findlay (1963), the most significant adaptive change to heat by cattle was attributed to changes in hair coat. Wooly coated animals were poorly adapted to heat stress. The principal factor affecting hair coat thickness is photoperiod. Findlay further indicated that although cattle may develop an acute respiratory alkalosis, profuse sweating is never observed in cattle. Also there is no evidence that efficiency of skin vaporization increases during acclimatition in cattle.

Physiology of Temperature Control

The control center for thermal regulation is the hypothalamus (Paine, 1976). Distefano and Stear (1969) proposed a model whereby the hypothalamic stimulus of the anterior pituitary caused the pituitary to release thyroid stimulating hormone (TSH). This resulted in increased thyroxine production from the thyroid gland. In turn, thyroxine level alters the metabolic rate of cells. This sequence of events may be depressed with adaptation to heat. Missouri workers (Johnson and Ragsdale, 1959) found that thyroid activity was depressed as a result of acute heat stress in cattle. They suggested that the thyroid is involved in long term adaptation to heat stress. A decrease in thyroid activity has been suggested to be associated with reduced gut motility and rate of digesta passage with heat stress (NRC, 1981).

Christison and Johnson (1972) found that when cattle were subjected to a moderate rise in temperature, plasma levels and turnover rate of cortisol increased. However, after seven to ten weeks of heat adaptation, plasma cortisol levels returned to the original levels and turnover rate was slightly lower than before heat stress was induced. They suggested that cortisol plays a role in the activation of heat release mechanisms and that the lower level after acclimatation was due to a lower basal metabolic rate of cells. More recent research indicates that the cause and effect may be opposite and that a lower basal metabolic rate is due to a lower level of cortisol. Paine (1976) in his review suggests that other hormones, including hydrocortizone, norepinephrine, epinephrine, glucagon, ACTH, and the somatotropic hormone may play roles in heat adjustment.

In a comprehensive study by Kamal et al. (1962), a variety of metabolic reactions were monitored in a group of dairy heifers. Holstein, Brown Swiss, and Jersey heifers raised at a constant temperature (10 and 27 C) for one year were exposed to rising environmental temperature (2 to 35 C) after they had been thermally equalized at 27, 32, and 11 C for about one month. Reactions of warm versus cold acclimated heifers were compared under various environmental temperatures.

With both groups of heifers, (those acclimated at 10 C and those acclimated at 27 C) as temperature was increased from 10 to 35 C, urine volume increased while urine specific gravity decreased. This was attributed to an increase in glucocorticoid secretion. High levels of glucocorticoids prevent release of antidiuretic hormone which would, in turn, increase urine secretion. Diuresis may have been due in part to a decrease in mineralocorticoid secretion, also.

Three reasons were given for the decrease in the specific gravity of the urine. First, potassium excretion was depressed by 70 percent at 35 C as compared to 10 C. Secondly, the increase in urine volume caused all urine constituents to be diluted. Finally, feed intake decreased. This would increase the amount of urea recycled and decrease the amount of urea to be excreted in the urine. Compared with the 27 C acclimated group, the 10 C group had a significantly greater increase in urine excretion and a somewhat faster rate of decrease in urine specific gravity when temperature was increased to 35 C. This suggests that the 27 C group had lower glucocorticoids, higher mineralcorticoids and probably higher antidiuretic hormone secretion than the 10 C group. Water consumption increased as temperature increased to 35 C with both groups of heifers. However, the rate of increase was faster for the heifers reared at 10 C than for those reared at 27 C.

Kamal et al. (1962) also examined the effects of heat stress on plasma protein content. Plasma volume and plasma protein content were inversely related. Heifers reared at 27 C had lower plasma volume and higher plasma protein concentrations than heifers reared at 10 C. Although both groups consumed about the same amount of water, the 27 C group lost more than twice as much water as the 10 C group. When exposed to rising environmental temperatures, both groups showed a decline in plasma protein contcentration. Although this may be due primarily to an increase in plasma volume, other factors may be involved. Nitrogen intake, depressed with rising temperature, could contribute to the decrease in plasma protein concentration. They also suggested that an increase in catabolic glucocorticoids may have contributed to the decreased concentrations of plasma protein. As environmental temperature was increased, plasma protein concentration decreased more slowly for heifers reared at 27 C than those reared at 10 C. This may be attributed to a lower secretion of glucocorticoids and the slower increase in plasma volume for the heifers reared at 27 C.

In the same study by Kamal et al. (1962) nitrogen retention decreased by about 100 percent as temperature increased from 10 C to 35 C. This supposedly was a result of increased glucocorticoids which are catabolic and enhance protein breakdown. Also, insulin and growth hormones, both of which are involved in protein anabolism, are inhibited by high levels of glucocorticoids. Heat also may increase protein ~~ca~~tabolism through direct action on gluconeogenesis not mediated by glucocorticoids.

But glucocorticoids have other effects not observed with heat stress. Glucocorticoids have been shown to cause hyperglycemia in cattle (Chung, 1958), mainly by enhancing gluconeogenesis, but also by inhibiting peripheral utilization of glucose (Ingle et al., 1953) and by inhibiting the hypoglycemic action of insulin (Bornstein and Park, 1953). Kamal et al. (1962) found that as the temperature increased from 10 C to 35 C, blood glucose concentrations decreased in both groups of cattle. An increase in glucocorticoids should cause the opposite. The decline in feed consumption could be responsible for the decline in blood glucose levels with heat stress (Leffel and Shaw, 1957). Also, a marked increase in respiratory activity, typical of heat stressed cattle, would increase utilization of blood glucose by the respiratory muscles and may outweigh hyperglycemic effects of glucocorticoids. A third possible reason for the decrease in blood glucose levels is dilution of plasma glucose due to an increased plasma volume. Although acclimatation had no effect on the direction of change in various physiological reactions to heat, it exerted an influence on the magnitude of the response. Cattle raised at warm temperatures were more sensitive and more stressed in a cold environment than cattle raised in a cool environment.

In conclusion, the zone of themoneutrality which was suggested by Kibler and Brody (1949) to be between 4 C and 16 C, can be shifted substantially up or down depending on the type of acclimatation.

Hair and Coat Color

Coat color plays a role in the amount of radiant energy that is absorbed by cattle coats and thus can influence heat tolerance of cattle in an outdoor environment (Stewart and Brody, 1954; Hutchinson and Brown, 1969). Radiant heat load has received less study than temperature and humidity since radiation is more difficult to control and replicate under specific environmental conditions.

Stewart and Brody (1954) reported that as radiation intensity increased, hair and skin temperatures in Holstein, Jersey, and Brahman cattle increased. However, respiration rate was not proportional to radiation intensity except in Brahmans. Work by Finch and Western (1977) indicated that natural selection has increased the proportion of cattle with light coat color in cattle herds exposed to the tropical environment of Kenya, Africa. At an altitude of 1400 m, dark cattle absorbed more solar radiation than light cattle, drank more water, lost less weight during a drought and gained weight faster after it. During the drought, more light than dark cattle died. However in the lowland areas, more dark than light cattle will die during a drought.

Schleger (1962) examined the effect of heat stress on cattle within a range of red colors. He found no tendency for dark red animals to exhibit more stress than light red animals. In fact, the intensity of red color and body temperature were negatively related. Furthermore, the correlation between the intensity of red color and rate of gain was consistently positive. The author suggested that the degree of red color may be more important as an index of metabolic status than of heat tolerance. His results cannot necessarily be extrapolated to a comparison of black versus white cattle or other color comparisons within a genetic type, however.

Several researchers have explored the relationship between body surface temperature and heat stress. Stewart and Brody (1954) found that darker colored cattle absorbed more radiation and had higher hair and skin temperatures than lighter colored cattle. Beakley and Findlay (1955) found that without radiant heat exposure, skin temperature of calves increased with increasing environmental temperature and humidity. After about 10 minutes, the skin had acquired a new stable temperature. Although they found no consistent differences in skin temperature between eight different places on the trunk, variations between measurements decreased as environmental temperature increased. These workers suggested that skin temperature by itself was not useful as an index of heat tolerance in cattle not exposed to radiation.

Shanklin and Stewart (1966) found that surface temperature decreased as humidity increased. This is opposite the response expected, since an increase in humidity would decrease the potential for surface vaporization and should increase surface temperature.

They postulated that with increased humidity, blood is shunted from the surface to the body interior. This shift would increase the heat stress but decrease surface temperature. Hence, body surface temperature would be unreliable as an index of heat stress under different humidity conditions.

Thickness of hair coat may also influence the surface temperature of cattle. Turner (1962) found that clipping the coat significantly increased growth rate of cattle during the summer. Berman and Kibler (1959) found that clipping the coat caused a decrease in respiration rate, total vaporization, ventilation rate and pulmonary vaporization while tidal air volume was nonsignificantly increased. Rectal temperature, a fairly accurate measure of deep body temperature, was not affected by clipping while body surface temperature was significantly increased (.26 C) with clipping. These changes may result from increased feed intake, however, and not be a direct result of clipping. Bianca (1959) noted that clipping decreased heart rate, salivation and frequency of defecation. Animals' mouths remained closed for a longer period of time and more time was spent ruminating.

Since the validity of the various indices of heat stress are not positive and many heat stress studies have not exposed animals to a radiant heat load, we monitored body surface temperature in conjunction with the more accepted measurement of respiration rate to determine the relationship between these two measurements in outdoor conditions.

Housing Systems

In recent years confinement systems have become more popular for feeding cattle. In our study, some of the cattle were housed in a confinement system known as a "teardrop" unit. This system consists of a long sloping floor that is two pens wide and about 40 pens long. The floor is slatted with shallow, teardrop shaped crevices between slats that are constantly or intermittently flushed with flowing water. Water, that flushes the length of the floor, runs into a pit at the end of the floor and is carried to a lagoon. The facility is not enclosed nor are there shades over the pens. The manager as well as the feedlot consultant for this lot indicated that summertime performance of cattle in the teardrop unit was substantially poorer than performance of cattle in neighboring dirt-lots. However winter performance between facilities was comparable. These indications led us to believe that heat stress may be involved. Furthermore, confined cattle have less space than cattle in dirt lots (1.95 m^2 vs 6.5 m^2) and thereby may be subject to greater heat stress.

Iowa research has indicated that confinement will depress gains (Self et al., 1975). Gains during the four summers were less for cattle in a confinement facility enclosed on three sides than for cattle in either sheltered or nonsheltered dirt-lot pens. But in five winter tests, confined cattle had rates of gain similar to those of sheltered cattle in the dirt-lots and greater than those of nonsheltered cattle in dirt-lots. The decreased gains of confined cattle during the summer in these studies could be attributed to the decreased feed intake though heat stress was not mentioned.

Minnesota researchers (Smith et al., 1972) compared five housing systems for feedlot cattle including two types of confinement facilities--the warm slat and the cold slat. Their warm slat facility is completely enclosed on all sides with slatted floors over a manure pit. The cold slat facility has one open side. Studies lasting about eight months each were conducted starting in November during the years 1969 to 1972. In both the warm and cold slat facilities, average daily gain decreased as space allowance was decreased from 1.55 to 1.30 square meters per head. Cattle confined in both the warm and cold slat systems had greater amounts of total body fat than cattle in the open lot as measured by kidney, pelvic and heart fat and backfat. Cattle in the open lot had slightly higher marbling scores.

In a subsequent trial, gain was greater for cattle with 2.32 square meters per head than cattle with 1.55 square meters per head in both the warm and cold slat facility (Smith et al., 1973). However, the feed intake within each facility was identical at both densities. Therefore, feed efficiency had substantially increased for the cattle at a density of 2.32 square meters per animal. Between facilities, the cattle in the warm slat system with 2.32 square meters per animal had faster daily gains than those in the cold slat system (1.68 kg and 1.53 kg). Although cattle raised in an open lot in this study had a greater feed intake than cattle in either the warm or cold slat facilities, daily gain tended to be about equal to that of cattle in the warm slat unit reflecting better feed conversion efficiency of confined cattle. This might be a result of differences in the amount of exercise under the different systems. In contrast with the previous study, the housing system had little influence on carcass characteristics of yearling steers in this study.

Breed Influences

In addition to environmental modifications to increase cattle performance during periods of heat stress, animal adaptability also might be improved genetically. Where heat stress is prevalent, cattle selected for feeding should carry some Bos indicus genes.

Bos indicus cattle are less affected by heat stress than Bos taurus cattle. Though a number of studies have sought what physiological mechanisms are responsible for this difference, the answer is not certain. The several theories include differences between breeds in surface area, basal metabolic rate, fat distribution and sweating.

The most common theory is that Bos indicus cattle, compared with Bos taurus cattle, have a greater body surface area relative to their body weight. The increased surface area allows dissipation of a greater amount of heat in a given period of time. Kleiber (1961) indicated that body size and metabolic rate per square meter of surface area were positively correlated. It has not been confirmed whether metabolic rate per unit surface area is independent of size. Kleiber (1961) later found that metabolic rate was proportional to body weight raised to a given power. According to Hafez (1968) Bos indicus cattle have a lower basal metabolic rate than Bos taurus cattle. In addition they digest feeds more completely, have greater metabolite absorption from the intestines, and will consume more dry matter per unit of body weight per day than Bos taurus cattle during periods of heat stress.

Ledger (1959) attributes part of the difference in heat tolerance of Bos indicus cattle to the distribution of body fat. At slaughter, Bos taurus cattle will have much more subcutaneous fat than Bos indicus cattle while Bos indicus cattle have more intermuscular fat. These workers proposed that subcutaneous fat acted as an insulator with the degree of insulation varying with fat thickness and that a thick layer of fat prevented heat dissipation.

Thompson et al. (1953) found that Brahman cattle dissipated a greater percent of their total body heat by evaporative cooling at high temperatures than European cattle. At air temperatures greater than 29 C, skin temperatures was lower in Brahman than European breeds. Finch et al. (1982) observed that the linear slope of the relationship between sweat rate and rectal temperature was greater for Brahman than for Brahman X Herford-Shorthorn or Shorthorn cattle. This helped explain why the range and mean rectal temperature for Brahmans were lower and little affected by heat stress. Although the sweating response of Shorthorn cattle approached a plateau, the sweating limit of Brahman and Brahman cross cattle was not reached. Although sweating was not related to grazing time or growth rate, it was negatively correlated with metabolic rate between animals within breeds. This indicates that combining the desirable traits of good heat adaptation and high metabolic potential in cattle may be difficult.

Diet Effects on Heat Stress

One of the major reasons for a decrease in feed consumption during periods of thermal stress is that the animal attempts to regulate its body temperature by decreasing the amount of heat that is generated during the processes of digestion and metabolism. This is commonly called the thermostatic theory of feed intake control and has been reviewed by McDonald et al. (1981). In a study by Lofgreen (1974) diets for steers were formulated to have a different heat increment while maintaining net energy for gain. Heat increment of the feed was reduced by reducing the roughage level, adding dried beet pulp, and increasing the fat content. Cattle fed the lower heat increment diet had greater feed intakes and rates of gain. Even though feed consumption was lower on the higher heat increment diets, the energy consumed was well utilized. This indicated that lowered gains during heat stress may be due to lower feed consumption and not due to a depression of energy utilization. Lofgreen (1974) also found that cattle on the low heat increment diets tended to grade higher and have more total carcass fat than cattle on high heat increment diets.

In work by Olbrich et al. (1973), Zebu cattle on a high roughage diet consumed more feed than cattle on a high concentrate diet during periods of heat stress. However, total caloric intake was less for the cattle fed high roughage diet. At a cooler temperature (9 C), cattle fed a high concentrate diet consumed more feed than cattle fed a high roughage diet. These diets may have provided more and less heat, respectively. Paine (1976) speculated that these feed preferences developed because of the duration of heat production from the two diets rather than being based on the total amount of heat produced. Rate of gain should be greater with high concentrate diets during heat stress since animals will consume more energy before the heat sensing mechanisms are triggered. Beef cattle may choose roughage diets to avoid heat surges of the "hotter" concentrate diet and to satisfy hunger for a longer time period (Paine, 1976).

With poultry, three different diet modifications have been used in attempts to alleviate heat stress. These are increased levels of supplemental dietary vitamin C (ascorbate), niacin and sodium bicarbonate.

Ascorbic acid. Thornton (1961) found that as environmental temperature was increased from 21 to 31 C over a period of one or two weeks, blood ascorbic acid levels dropped. Addition of iodinated casein to the diet increased blood ascorbic acid levels. He suggested that the chicken either partially lost the ability to synthesize ascorbic acid or the capacity of blood to transport this vitamin decreased as environmental temperature increased.

Supplementation of the diet with ascorbic acid has been shown to aid in maintaining body temperature of chicks in either a warm or cool environment (Thornton, 1962; Grimes and Moreng, 1965; Lyle and Moreng, 1968). Work by the latter authors indicated that long term supplementation of ascorbic acid prior to periods of heat stress is unnecessary and that feeding over a short term was sufficient. Response to elevation of temperature to 29 C for one week was similar for birds which had received ascorbate for either a long and a short term.

Depletion of adrenal ascorbic acid and adrenal cholesterol together with increased plasma corticosteroids appear to be reliable indicators of stress in fowl (Siegel and Gross, 1965; Thaxton et al., 1968). Nathan et al. (1976) reported that during short term heat stress, leucocyte counts decrease while ascorbic acid concentrations in plasma and in leucocytes increase.

In laying hens, supplemental dietary ascorbic acid levels of 25, 75, and 400 ppm increased egg weight and egg shell thickness (Perek and Kendler, 1961). Egg production response was linearly correlated to the level of vitamin C. However, Lyle and Moreng (1968) concluded that non-layers do not respond to the same degree as layers with regard to the influence of ascorbic acid on body temperature regulation. This suggests a metabolic difference. Growth response from chicks to supplemental ascorbic acid has been inconclusive, with several reports of beneficial effects (March and Biely, 1953; Combs et al., 1958; Oluyemi and Adebanjo, 1979) and one report of no benefit (Gogus and Griminger, 1959).

A year long study by Singh and Merilan (1957) examined the influence of temperature on vitamin levels in the blood of Brahman, Shorthorn, and Santa Gertrudis cattle. Brahman cattle raised at 27 C tended to have higher blood ascorbic acid levels than those raised at 10 C while Shorthorn and Santa Gertrudis tended to have slightly lower blood ascorbic acid levels when raised at 27 C than at 10 C. Blincoe and Brody (1951) indicated that blood ascorbic acid levels declined as environmental temperature increased with the decline most pronounced above 27 C. Dietary ascorbic acid supplementation for ruminants may not prove useful, however, since ascorbic acid is quickly destroyed in the rumen (Singh and Merilan, 1957).

Niacin. This vitamin is an effective vasodilator in humans. Spies et al. (1938) indicated that niacin produced dilation of the small vessels of the skin of the face and upper part of the trunk of healthy humans. This was accompanied by increased temperature, flushing, burning, and itching. Goldsmith and Cardill (1969) found that niacin increased blood flow in the hand and forearm without concomitantly changing blood pressure or pulse rate. They found no appreciable change in metabolic rate and concluded that the vasodilation was not compensatory to increased heat production; rather vasodilation was due to a local effect on the arterioles in the skin. This appears to be mediated by the release of endogenous prostaglandins (Kaijser and Eklund, 1979). Increased blood flow to the body surface could speed heat dissipation to reduce heat stress.

With regard to temperature effects on blood niacin levels in cattle, Singh and Merilan (1975) found that Shorthorn cattle raised at 27 C had distinctly lower niacin levels than those raised at 10 C or Brahman and Santa Gertrudis raised at 27 C. After the second month, Brahman cattle at 27 C maintained higher blood niacin concentrations than both Shorthorn and Santa Gertrudis cattle at the same temperature.

Bicarbonate. According to Baker and Harrison (in Trenkle et al., 1979) plasma pH is maintained in a narrow range of 7.36 to 7.44. Under heat stress conditions, when animals begin panting, carbon dioxide may be excessively exhausted from the lungs. Removal of carbon dioxide from the blood stream results in a condition known as "respiratory alkalosis". With respiratory alkalosis, the pH of the blood rises to an abnormal level. To compensate for this rise, the renal tubules excrete a greater amount of sodium and bicarbonate in the urine. Possibly, supplemental dietary sodium bicarbonate could replace this loss and restore buffer concentrations of the blood.

Florida workers evaluated the influence of supplemental sodium bicarbonate (0 and .85%) and/or potassium bicarbonate (0 and 1%) and total dietary potassium (.8 and 1.2%) on feed intake during periods of heat stress with lactating dairy cattle (Schneider et al., 1982). Potassium bicarbonate tended to decrease feed consumption (17.4 vs 19.5 kg/day) while sodium bicarbonate tended to increase feed consumption (18.7 vs 18.2 kg/day). Mean feed intake also increased with higher levels of dietary potassium (18.7 vs 18.1 kg/day, $P<.05$). Work by Johnson (1970) indicated that sodium and potassium secretion in the sweat of cattle increased significantly with increasing air temperature and that secretion of potassium was four to five times greater than sodium. However, total secretion of these two electrolytes was no more than one to three percent of daily sodium or potassium intake. Kellaway et al. (1977) fed supplemental sodium bicarbonate to calves at levels of 0, 3, 6, and 9 percent of the diet. Supplementation caused successive increases in blood pH (7.37, 7.39, 7.42 and 7.44 for the 4 diets, respectively). Partial pressure of carbon dioxide increased by 46.3, 47.7, 51.0 and 54.5%, respectively. Environmental conditions were not discussed, however it has been suggested that under heat stress conditions, supplemental sodium bicarbonate would not aid in restoration of the acid-base balance of the blood in cattle.

CHAPTER III

HEAT STRESS IN FEEDLOT CATTLE: RELATIONSHIPS BETWEEN COAT COLOR, RESPIRATION RATE AND BODY SURFACE TEMPERATURE

Abstract

The relationship of hair coat color (red vs. black) with respiration rate and body surface temperature was examined with cattle at a feedlot near Garden City, KS. A group of 454 steers, predominantly Hereford and Angus breeding, were used. Animals were sorted by hair color (red or black) and allotted to four confinement pens at a density of 1.95 square meters per animal, or to four conventional dirt lot pens with 6.5 square meters per animal. On three different days of the trial, respiration rate and body surface temperature were measured on these steers and on white Charolais or Charolais crossbred steers in other pens. Respiration rate and body surface temperature both peaked at noon or slightly later in all groups although ambient temperature did not peak until 1800. Respiration rate by this time had decreased. Differences due to coat color were not detected during the early morning or late evening, but during the hotter period of the day, both respiration

rate and body surface temperatures peaked at higher points for black and red-haired cattle than for white-haired cattle. Comparison of predominantly black with predominantly white Holstein steers in a single pen during the hot part of the day also revealed a correlation between respiration rate and body surface temperature, with black Holsteins having a respiration rate 35% greater (114.1 vs 84.4 breaths/min; $P<.05$) and a body surface temperature 44% greater (41.3 vs 34.2 C; $P<.05$) than white Holsteins.

Introduction

Summertime performance of some cattle in the southern Great Plains can be substantially decreased due to heat stress. Feed intake of heat stressed cattle is typically decreased. This leads to slower gains and a lower efficiency of feed use. Factors which dictate the amount of heat stress an animal can withstand may be either related to weather conditions (temperature, humidity, radiation) or to animal conditions (basal metabolic rate, hair coat color and thickness). Research by Stewart and Brody (1954) showed that darker coat colors will absorb greater amounts of solar radiation in a non-shaded environment. Thereby, color of cattle in a non-shaded feedyard may have a substantial impact on heat tolerance. Finch and Western (1977) indicated that in areas of prevailing heat stress, natural selection has led to a higher proportion of light colored cattle. Many of the cattle which succumb to heat stress in non-sheltered, non-shaded feedlots are black in color. The objective of this research was to evaluate relationships among coat color, body surface temperature and respiration rate of feedlot steers.

Experimental Procedure

This experiment was conducted in cooperation with a feedlot located in Garden City, KS. This study involved 978 feedlot steers. One group of 454 steers of English breeding averaging 352 kg were sorted by color (red or black) and allocated to either four drylot or four confinement (non-shaded) pens with duplicate pens of cattle of each color. Confinement pens provided 1.95 m^2 of space per animal with either 100 (red) or 50 (black) steers per pen. The open lot pens provided greater than 6.5 m^2 of space per animal with either 40 (red) or 37 (black) steers per pen. A second group of 524 steers of mixed color (red, black, and white) averaging 398 kg were randomly allotted to three replicated treatments in the confinement pens. One group was intended to be non-sprinkled with 2.42 m^2 of space per animal. A second group at 1.95 m^2 per animal was intended to be sprinkled while a third group kept at 1.95 m^2 per animal was intended to be non-sprinkled. Sprinklers were thermostatically controlled and operated for five minutes every half hour when the ambient air temperature exceeded 26.7 C.

Four days after the initiation of treatments, ten animals on the non-sprinkled treatment died from heat stress. Nine of these ten animals had black hair color. Subsequent to this time, all cattle in confinement pens were sprinkled to avoid further death loss.

In addition to the cattle specifically allotted to the experiment, a group of Holstein steers in another confinement pen with no shade were studied to more directly correlate respiration rate and body surface temperature within a single breed. Other comparisons of black versus red cattle differed genetically. The comparison with Holstein steers also removes the possible interaction of Brahman crossbreeding with coat color. Yet, all red and black steers were from South Dakota and supposedly had no Brahman breeding. Respiration rate and surface temperature were measured simultaneously with predominantly white and predominantly black Holstein steers.

Respiration rates and body surface temperatures were measured on three different dates during the trial (7/31/82, 8/21/82, 9/4/82). At each time, respiration rates and surface temperatures were measured on five to ten animals per pen. Animals selected were those near enough to measure accurately, but both measurements were not necessarily on the same animal within or between periods. Body surface temperature was measured with a gun type, battery operated infra-red thermometer that collects infrared energy from a distance of up to 100 m. Respiration rates were calculated by stopwatch timing of the number of seconds required for an animal to inhale 30 times and calculated as breaths per minute. Ambient air temperature and relative humidity were monitored continuously, and black bulb temperatures measured intermittently. A high energy feedlot diet containing cracked corn, corn silage, soybean meal, was fed to all pens. All results were analyzed using the Analysis of Variance procedure (SAS, 1979).

Results and Discussion

Weather data for the three data collection periods are provided in table 1. These represent times at which respiration rates and body surface temperatures were measured (tables 2 and 3). The highest air and black bulb temperatures for each collection period were at 1600 or 1630. Based on the hygrothermograph readings, ambient temperature peaked about 1800 each day.

On the first measurement date, white cattle had significantly lower ($P<.05$) respiration rates than either black or red cattle during all five time periods (table 2). Except for the first period, which was near sunrise, and the final period, near sundown, the respiration rate was consistently greater for black than red cattle. Sprinklers began operating during the 1330 time period. Sprinkling may have confounded surface temperature measurements (table 3) though all cattle appeared dry when surface temperature was measured. Nevertheless, on subsequent measurement days sprinklers were turned off while measurements were taken.

Weather conditions for monitoring heat stress on August 21 were less than ideal. Fog and mist were present during the morning. From 1200 to 1600, cloud cover was intermittent. Cloud cover appeared to influence body surface temperature more than it influenced respiration rate. This contrasts with sunny days (July 31 and September 4). Red cattle had a higher respiration rate throughout the day than black cattle. Respiration rate differences between black and red cattle on all three dates were nonsignificant ($P>.05$). On August 21 white cattle had respiration rates similar to both black and red cattle except at 1600 when respiration rate was lower ($P<.05$) for white than red and substantially less than black cattle.

The final measurement day, September 4, was sunny all day. Red cattle had lower respiration rates than black cattle except at 1630. White cattle had lower respiration rates than either black or red cattle until 1030, similar rates from 1030 until 1630, and lower rates until sundown.

On the two later measurement dates, respiration rate peaked at 1200 to 1330 though ambient temperature did not peak until 1800. On the final measurement day, respiration rate had decreased substantially by the time ambient temperature peaked. Earlier in the summer, respiration rate was slightly greater at 1630 than at 1330. The reason that respiration rate peaked before ambient temperature is not known though several explanations are possible. Stewart and Brody (1954) indicated that in Bos taurus cattle, respiration rate rises exponentially in the temperature range 60 to 80 degrees Farenheit. Furthermore, Bianca and Findlay (1962) indicated that under severe heat stress, animal ventilation is bi-phasic. The first less-stressed phase consists of rapid shallow breathing while during the second more extreme phase, breathing is slower and deeper. This would suggest that August 21 and September 4 were more stressful days than July 31. Ambient temperature on

July 31 was intermediate to the other two dates with September 4 being the highest. Relative humidities on August 21 and September 4 were higher than July 31. A second explanation for the decrease in respiration rate prior to the time of maximal temperature lies in the effect of radiation. On July 31 the black bulb temperature reached 43.3 C at 1330 and maintained this temperature through 1630. On August 21, the black bulb temperature peaked at 43.9 C at 1200 and fell to 40.0 C by 1600. On September 4, black bulb temperature reached 38.8 C at 1330 but maintained this temperature until 1630. Perhaps the higher amount of solar radiation on the first date increased the heat input which continued to elevate respiration rate. A third explanation is that by the second and third measurement dates cattle had become acclimated so that respiration rate was less affected by heat stress. A final explanation would be that at mid-day, although ambient temperature had not peaked, radiant heat load was much greater due to the overhead position of the sun which exposed more of the animal's body to the radiant heat load than later in the day.

Humidity as well as temperature is an important factor in heat stress. Bianca (1962) reported that a weighting of .35 for dry bulb and .65 for wet bulb temperature was most closely correlated with the rectal temperature responses of Ayrshire calves in a climatic room. Solar radiation and wind convection are additional variables important to cattle in a non-sheltered, non-shaded environment.

Body surface temperatures (table 3) followed trends in respiration rate. On July 31, during the warmer part of the day and into the evening, white animals had lower body surface temperatures than red and black animals. Black animals tended to have slightly greater surface temperatures than red animals throughout the day. However, sprinklers began operating at 1330 which could have a pronounced effect on surface temperatures due to evaporative cooling. On both August 21 and September 4, the days that sprinklers were shut off, white cattle had significantly lower ($P<.05$) body surface temperatures than both black and red cattle from 1030 through 1930. On all dates red cattle tended to have lower body surface temperatures than black cattle throughout the day, although on August 21, surface temperatures were subject to variation due to intermittent cloud cover.

Surface temperatures were always measured on the sunny side of the animal since surface temperature on the side of a steer exposed to direct solar radiation was 5 to 8 C higher than on the non-exposed side. Rate of change in surface temperature with time of exposure to the sun was not measured. Beakley and Findlay (1955) indicated that when environmental temperature is changed, the skin temperature of a calf will acquire its new value within 10 minutes. This time may not be appropriate with exposure to solar radiation, however. Cursory observations suggested that in three to four min, skin temperature adjusted to exposure to solar radiation.

Beakley and Findlay (1955) indicated that skin temperature alone is not a useful index of heat tolerance for cattle. Variation caused by radiation or moisture on the hair coat and the thickness or density of the hair coat certainly can influence surface temperature. However, measurement of body surface temperature using an infra red heat sensing gun may hold some merit since surface temperature can be measured easily. Surface temperature can be measured with dozens of steers in a large pen with less disturbance than measurement of internal temperature. Implanted transmitting thermometers would be a desirable, less invasive system to monitor rectal temperature of steers.

Comparison of six predominantly black with six predominantly white Holstein steers in a single pen at a single time (table 4) revealed a positive correlation between respiration rate and body surface temperature. Respiration rate was 35% greater for black than white Holsteins while body surface temperature was 14 percent greater for black than white Holsteins. This contrasts with results of Stewart and Brody (1954) who indicated that radiation, air temperature and relative humidity caused no appreciable difference in respiration rate response between predominantly black and predominantly white Holsteins. Relative thermal input from metabolic and solar sources may explain the difference in results.

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TABLE 1. WEATHER DATA ON MEASUREMENT DATES

Time	Ambient Air, C			Relative Humidity, %			Black Bulb, C		
	7/31	8/21	9/4	7/31	8/21	9/4	7/31	8/21	9/4
0730	14		17	90		64	ND[a]		23
0800		19			90			25	
1030	23		23	44		55	40		33
1200		21			78			44	
1330	26		31	32		37	43		39
1600		21			78			40	
1630	29		32	30		34	43		39
1930	29		31	41		36	31		ND

[a] Not determined.

TABLE 2. RESPIRATION RATES OF CATTLE WITH DIFFERENT COAT COLORS

	Date of Measurement								
	7/31			8/21			9/4		
Coat color	Red	Black	White	Red	Black	White	Red	Black	White
Time	Respiration rate, breaths/min								
0730	76.5^{a}	75.3^{a}	59.1^{b}				40.4^{ab}	43.9^{a}	28.8^{b}
0800				70.1	59.0	62.8			
1030	106.1^{b}	113.8^{a}	67.3^{c}				95.3	97.1	79.4
1200				138.7	132.9	137.1			
1330	126.1^{a}	129.6^{a}	98.1^{b}				131.8	134.5	132.1
1600				134.0^{a}	126.2^{ab}	109.9^{b}			
1630	134.9^{a}	138.0^{a}	87.6^{b}				113.3	106.2	102.7
1930	105.8^{a}	103.5^{a}	66.3^{b}				82.9	86.1	77.9

[a,b] Means within a date and time with different superscripts differ ($P<.05$).

[c] Standard errors for means at consecutive times: for 7/31-4.69, 4.97, 5.77, 4.92, 5.85; for 8/21-5.84, 6.84, 6.46; for 9/4-3.60, 6.79, 6.07, 6.07, 6.08.

TABLE 3. SURFACE TEMPERATURES OF CATTLE WITH DIFFERENT COAT COLORS

	Date of Measurement								
	7/31			8/21			9/4		
Coat color	Red	Black	White	Red	Black	White	Red	Black	White
Time	Body surface temperature, C								
0730	31.7	33.5	31.5				29.1	29.8	
0800				29.9	31.2	30.4			
1030	40.2^{b}	45.0^{a}	35.9^{c}				39.1^{a}	40.9^{a}	32.7^{b}
1200				40.5^{b}	46.1^{a}	35.6^{b}			
1330	38.9	39.6	33.2				41.8^{a}	42.8^{a}	36.7^{b}
1600				42.2^{a}	43.0^{a}	36.2^{b}			
1630	38.9	39.6	33.2				39.8^{a}	41.6^{a}	34.4^{b}
1930	28.9^{ab}	30.3^{a}	28.0^{b}				30.1^{a}	30.3^{a}	29.3^{b}

[a,b] Means within a date and time with different superscripts differ ($P<.05$).

[c] Standard errors for consecutive surface temperature means: for 7/31-1.13, .83, 1.42, 1.56, .34; for 8/21-2.16, 1.67, .60; for 9/4-1.15, 1.14, .75, .90, .24.

TABLE 4. COMPARISON OF BLACK VS WHITE HOLSTEIN STEERS (9/4/1982)

	Predominant coat color		
	Black	White	SE[a]
Breaths/min	114.1[b]	84.4[c]	4.40
Body surface temperature, C	41.3[b]	34.2[c]	.67

[a] Standard error of the mean with 6 animals per color.

[b,c] Means in a row with different superscripts differ ($P<.05$).

CHAPTER IV

HEAT STRESS IN FEEDLOT CATTLE:
THE INFLUENCE OF ANIMAL DENSITY, COAT COLOR, FLOOR TYPE AND SPRINKLING ON HEAT STRESS, PERFORMANCE AND FEEDING BEHAVIOR.

Abstract

The influence of confinement density, coat color (red or black) and floor type (confinement or dirt-lot) on heat stress and performance of steers was measured in a commercial feedlot using 978 cattle in 14 pens. An animal density of 2.42 square meters per animal did not increase gain or efficiency of cattle above that attained with 1.95 square meters per animal, but the confinement system depressed gains by over 32% ($P<.05$) compared with the dirt-lot pens in which steers had 6.5 square meters per animal. This difference was primarily due to decreased intake of feed which may be associated with increased heat stress. Averaged across hair coat colors, respiration rates during the hottest part of the day on all dates of measurement were greater for steers confined to "teardrop" floor pens than for steers in dirt-floor pens by 9.8

percent (19 breaths per min). This suggests that the "teardrop" system resulted in increased heat stress of steers.

Feeding behavior of steers on concrete floors appeared to be slightly different from steers in drylot pens, with a higher percentage of steers eating during the night hours and fewer eating during the middle of the day (10 am to 3 pm) for steers in "teardrop" pens. Black steers, compared with red steers, spent less time at the feed bunk in the afternoon and evening and more time feeding in the morning hours.

Introduction

Increased land values are forcing cattle producers to make maximum utilization of their acres for producing crops for mechanical harvest for feeding to cattle in a minimal amount of space. This has led to development of feedlots in many parts of the country. Feedlots spare land for crop production, can decrease the labor and energy requirements for cattle feeding, and permit the use of scientifically formulated least-cost diets for growing and finishing of beef cattle. Most feedlots are located in more arid regions of the U.S. to avoid the accumulation of waste and mud. Dirt pens have been commonly used. These provide about 6.5 square meters of space per animal. With cement floors and automated waste disposal methods, space becomes more expensive and the space allowance must be decreased below this point. With tight confinement, overhead construction to protect cattle from the environment can be economical where environmental conditions are unfavorable only if space allowance is limited.

Recently, "teardrop" flooring has become popular for feeding cattle in confinement. This flooring system is characterized by flushing water through gutters shaped like teardrops between slats of the concrete floor. Flushing may be constant or intermittent, water may be recycled and the liquid waste can be used for irrigation. Performance of cattle fed in a teardrop system during the summer may be substantially poorer than for cattle fed in conventional dirt-lot pens according to some feedlot managers. In contrast, performance often favors cattle in a confinement facility during winter months. This suggests that the depression in performance is not due to the confinement system, but instead is due to an interaction between the system and the summer environment. Assuming that the depression in performance may be related to heat stress, we approached the problem from three angles which may relate to heat stress.

First we tested the effect of lot type on performance. Secondly we tested the effects of coat color and animal density on heat stress and performance of cattle in confinement pens. In the third comparison, we decided to test the effect of intermittent sprinkling on performance of steers in confinement pens. Ambient (dry bulb) and black bulb temperature and relative humidity were monitored on three separate dates during the trial and performance of groups divided by density and coat color were measured.

Carcass weights, quality and dressing percentages were calculated from data provided by the slaughter plant.

Experimental Procedures

This experiment was conducted in cooperation with a feedlot located in Garden City, KS and involved 978 feedlot steers. One group of 454 steers of English breeding averaging 352 kg were sorted by color (red or black) and allocated to either four drylot or four confinement (non-shaded) pens with duplicate pens of cattle of each color. Confinement pens provided 1.95 m^2 of space per animal with either 100 (red) or 50 (black) steers per pen. The open lot pens provided more than 6.5 m^2 of space per animal with either 40 (red) or 37 (black) steers per pen. A second group of 524 steers of mixed color (red, black, and white) averaging 398 kg were randomly allotted to three replicated treatments. One group was intended to be non-sprinkled with 2.42 m^2 of space per animal while the second group at 1.95 m^2/animal was intended to be sprinkled. Sprinklers were thermostatically controlled and operated for five minutes every half hour when the ambient air temperature exceeded 26.7 C.

Four days after the initiation of treatments, ten animals on the non-sprinkled treatment died from heat stress. Nine of these ten animals had black hair color. Subsequent to this time, all cattle in confinement pens were sprinkled to avoid further death loss.

Daily gain was monitored in two phases. The first phase was from the beginning of the trial (July 18, 1982) until September 10. This was the hottest part of the summer. The second phase lasted from September 10 until the end of the trial (October 21) to determine if cattle in confinement pens would make compensatory gains. Dressing percentages and mean carcass grades were calculated from final full pen weights (minus 5 percent for shrink) plus information on carcass weights and grades supplied by the packing plant.

Respiration rates and body surface temperatures were measured on three different dates during the trial (7/31/82, 8/21/82, 9/4/82). These measurements were taken on five to ten animals per pen at each time period. Animals selected were those near enough to measure accurately, but both measurements were not necessarily on the same animal within or between periods. Body surface temperature was measured with a gun type, battery operated infra-red thermometer that collects infrared energy from a distance of up to 100 meters. Respiration rates were calculated by stopwatch timing of the number of seconds required for an animal to inhale 30 times and calculated as breaths per minute. Ambient air temperature and relative humidity were monitored continuously and black bulb temperature was measured intermittently. The diet was a high energy feedlot diet consisting of cracked corn, corn silage, soybean meal and was fed to steers in all pens. All results were statistically analyzed using the Analysis of Variance procedure (SAS, 1979).

Results and Discussion

Four days after the trial began, ten animals died on the non-sprinkled treatment. Other feed yards near Garden City also lost cattle that afternoon. Hygrothermograph recordings indicated that the ambient air temperature at the feedlot on that day peaked at 37 C at 1800 with a relative humidity of 23 percent. These conditions were not remarkably different from conditions on previous or subsequent days. Further weather data gathered at the Garden City Experiment Station of Kansas State University, Garden City, KS, about 10 km from the feedlot, indicated that average wind speed for that day was 3.2 km per hour, considerably less than days before and after this date. Low wind speed would reduce evaporative heat loss, especially with the more tightly confined cattle. This decrease in air movement may have been the factor which precipitated the death loss. Since none of the cattle on the sprinkled treatments died, the evidence indicates that sprinkling reduced heat stress.

Although we were unable to monitor the effects of sprinkling on performance, several previous studies have shown beneficial effects of sprinkling. Much of this work has been conducted in the Imperial Valley of Southern California. Cattle were sprinkled for one minute every 30 min during which ambient temperature exceeded 27 C in a study by Morrison et al. (1973). Sprinkled cattle consumed significantly more feed and gained significantly faster than the non-sprinkled control cattle, but feed conversion efficiency was not affected. In their trial, animals were provided with shade. Our cattle were not provided with shade, so we might expect an even greater response to sprinkling. Sprinkling may not improve performance if humidity is sufficiently elevated to reduce evaporative loss or if mud accumulates in pens.

Morrison et al. (1973) also compared performance of sprinkled animals to that of cattle in a refrigerated (24 C) barn. Sprinkled cattle had slightly higher respiration rates and rectal temperatures than refrigerated cattle, but performance of the two groups was comparable. In a subsequent experiment, sprinkling for one min every 30 min greatly improved feed intake and rate of gain and slightly improved feed conversion efficiency (Lofgreen et al., 1973). Sprinkling one min every 60 min also improved performance but to a lesser degree. However, when heat stress was less and cattle approached final weights, sprinkling appeared to be detrimental. Results from another experiment confirmed this. Sprinkling improved the performance of cattle put on feed at 227-318 kg but did not improve performance of heavier cattle (363-386 kg) which had been acclimated to the conditions for some time (Morrison et al., 1974). In a Kansas study (Nichols et al., 1982), cattle were sprinkled for two min every 30 min during which ambient temperature exceeded 27 C. Sprinkling increased daily gain by 16 percent ($P<.05$) and feed efficiency by 14 percent. The ambient temperature at which sprinkling becomes both beneficial and economical may vary with wind speed, radiant heat load, humidity level and other weather and animal factors.

Animal density of cattle within the confinement unit had little effect on animal performance (table 1). Cattle with 2.42 square meters per animal had feed intakes, daily gains, feed conversion efficiencies and dressing percentages not differing from that of cattle at a density of 1.95 square meters per animal. Efficiency of energy utilization, calculated from gains and feed intakes and expressed as calculated metabolizable energy content of the diet, did not differ with animal density. Although cattle performance must be reduced at some point by crowding of animals, the difference between 1.95 and 2.42 square meters had little effect on performance in this study.

In a study from California, Lofgreen et al. (1973) demonstrated that performance was superior when cattle had 3.7 square meters than when they had 1.95 square meters per animal. They suggested that space allowance interacted with heat stress, since more closely confined cattle radiate body heat to each other rather than to the atmosphere. In addition, air movement to carry heat away is reduced when cattle are closely confined.

Decreasing animal density also will usually increase space at the feed bunk in addition to space in the pen. More space per animal may be desirable to increase performance in a confinement facility, but high costs for construction of increased space makes loose confinement an economic disadvantage. Bunk space, watering space and cost of floor and buildings all need to be considered when designing facilities.

Performance of cattle in the teardrop unit was significantly poorer than performance of cattle in the conventional dirt-lot pens (tables 2 and 3). Averaged across cattle with both red and black hair coats, gain was 36% greater ($P<.01$) for cattle in dirt-lot pens than for cattle in confinement pens during the hottest part of the summer. The difference was 39% ($P<.05$) during cooler weather. suggesting that cattle did not make compensatory gain following the heat stress period.

Feed conversion efficiency across the total trial favored ($P<.05$) cattle in the dirt-lot pens by 12%. Much of this advantage in efficiency can be contributed to 32% greater ($P<.01$) feed intake by the cattle in dirt-lot pens. To more precisely determine how much of this advantage can be ascribed to the difference in feed intake, the metabolizable energy (ME) content of the diet was calculated. This calculation is based on the net energy equations and adjusts feed efficiency for differences in feed intake. Calculated ME of the diet was 4.4 percent greater ($P<.10$) for the cattle in the dirt-lots than for cattle in confinement pens. This suggests that energetic efficiency was reduced in the teardrop unit more than would be expected from the decrease in feed intake alone.

Work by Kelley et al. (1967) suggested that at a constant feed intake, an increase in ambient temperature increased the molar percentage of acetate and decreased the molar percentage of propionate in the rumen. Though ruminal concentrations of volatile fatty acids (VFA) are not necessarily related to ruminal production rates of VFA, an increase in acetate production would decrease the

ME content of the diet. A decrease in the total VFA concentration may be associated with reduced ruminal motility at high ambient temperatures (Attebery and Johnson, 1969). These workers found that the amplitude of ruminal contractions was decreased and the profile of VFA was altered when cattle were exposed to 38 C for five days. In contrast, exposure to 35 C for one or two days did not change ruminal motility or total VFA levels. A decrease in ruminal motility with heat stress also could reduce both rumination and digestibility of a poorly processed diet. This may be countered by a greater retention time in the rumen which may increase absorption. Olbrich et al. (1973) found no influence of ambient temperature on digestibility and could detect no significant difference in dry matter digestibility between heat and cold tolerant cattle. Nevertheless, the NRC publication on environmental stress concluded that digestibility will increase with heat stress (NRC, 1981).

The indices of heat stress used in this trial were respiration rate and surface temperature. Unfortunately, transmitting thermometers were not available. Cattle were not tame so that rectal temperatures could not be obtained except by working cattle through chutes. Stress of working cattle in the heat would have reduced performance and may have caused death loss of animals.

On July 31, respiration rates were 28 percent greater ($P<.05$) for cattle in confinement than in dry-lot pens (table 4). Confined cattle tended to have higher respiration rates throughout the day though body surface temperature was variable. This is probably due to sprinkling of confined cattle after 1300. Sprinklers were turned off on subsequent measurement dates to avoid this complication.

On August 21, respiration rate was 10 percent greater for confined cattle at 1200 (table 5). Body surface temperature at 0800 was 11 percent greater ($P<.05$) for cattle in confinement pens (table 6). But by 1200, black cattle in dry-lot pens had higher body surface temperatures than either group of red cattle. Surface temperature of black cattle in confinement was 10 percent greater ($P<.05$) than that of confined red cattle, and overall, the surface temperature of dry-lot cattle was 5 percent greater than that of cattle in confinement.

On September 4, respiration rates were greater for cattle in confinement throughout the day except at 0730 but no effect of coat color was detected (table 7). Lot type had no significant effect on body surface temperature (table 8) although cattle in confinement had slightly higher surface temperatures except at 1630.

Based on respiration rate measurements, steers in confinement appeared to be more heat stressed than cattle in dry-lot pens, possibly due to the greater cattle density in the confinement lot. The water passing through the teardrop system may have modified the environment and heat stress, as well. Constant flushing and intermittent sprinkling in the teardrop system would be expected to increase the humidity locally, but no humidity or temperature difference was apparent between confinement pens and dirt-lot pens by hygrothermographs sensing conditions 1.2 meters above the surface. Constant flushing of recycled water held the concrete surface temperature below 40.6 C. This compares with maximum soil surface temperatures of 54 to 60 C. The black soil was apparently heated by solar radiation. Such heating of the soil would be expected to be shallow and might be influenced by soil color and reflection.

Recycled water used to flush the floor generally increased in temperature by 1 to 2 C with flushing through the teardrop system during the warmest part of the day. This suggests that during the day, water flushing was decreasing the surface temperature. In contrast, during the night, flushing held the night temperature of the floor higher than that of the soil since temperature of the water was generally above temperature of the air at night.

Feeding behavior was measured at half hour intervals from midnight to midnight. Subdivided by floor type, results are illustrated in figure 1. Feeding intensity peaks were higher for steers in dry-lot pens than steers on the teardrop floor. This suggests that bunk space availability may have limited access to feed for cattle confined in teardrop pens. Though feeding was most intense shortly after cattle were fed, time of feeding appeared somewhat changed by floor type, with a lower percent of the steers in confinement than in dry-lot pens eating during the middle of the day (1000 to 1500). In addition, a higher percent of steers in confinement were eating before sunrise. Several factors may be involved. Cattle in confinement probably ate less during the day due to the thermogenic effects of feed intake. The heat increment produced by digestion of feed would add to the discomfort of heat stress. In addition, feeding at night would help compensate for limited bunk space, and less aggressive cattle may eat when there is less competition for feed.

The peak times of feed consumption during hot weather for cattle in dry-lot match with the report of Ray and Roubicek (1971). In comparing feeding behavior during summer and winter, they found that during the hot summer, frequency of eating activity during midday was decreased, the afternoon feeding peak was delayed, and the frequency of feeding during the early evening hours was increased.

The feeding pattern of steers classified by red and black coat color is presented in figure 2. More black steers tended to eat from 0700 until 1200, while from 1200 to 1930, more red steers were at the feed bunk. Higher surface temperatures and respiration rates for black than red cattle may have reduced their desire to eat during the hotter hours of the day.

These data indicate that during the summer months cattle should be fed by dawn to insure maximum feed intakes in the morning. The evening feeding time is less critical, but if feed is present, some cattle may begin eating as early as 1400 or 1500.

For confined cattle fed twice daily, intake may be greater if a larger proportion of the feed is placed in the bunk at the evening feeding than at the morning feeding. Even though slight differences were observed in the feeding behavior of red and black cattle, developing different feeding systems for cattle based on color needs further investigation.

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TABLE 1. INFLUENCE OF SPACE ALLOWANCE ON STEER PERFORMANCE

Surface area per animal, m^2	1.95	2.42	SE[a]
Steers	100	200	
Pens	2	4	
Daily gain, kg			
7/18 to 9/10	1.24	1.15	.23
9/10 to 10/21	.55	.60	.02
7/18 to 10/21	1.01	.94	.06
Daily feed, kg	8.75	8.39	.22
Feed/Gain ratio	8.73	8.89	.51
Metabolizable energy, mcal/kg	2.75	2.71	.05
Dressing percent	64.7	64.3	.20
Percent choice carcasses	76.5	80.0	2.75

[a] Standard error of the mean

TABLE 2. INFLUENCE OF PEN TYPE ON ANIMAL PERFORMANCE

Pen type	Drylot	Confinement	SE[a]
Steers	154	300	
Pens	4	4	
Daily gain, kg 7/18 to 10/21	1.51[b]	1.14[c]	.31
Daily feed, kg	10.5[b]	8.9[c]	.31
Feed/Gain ratio	7.01[d]	7.85[e]	.21
Metabolizable energy mcal/kg	2.85	2.73	.05
Dressing percent	63.2	63.5	.86
Percent choice	80.8	77.3	5.12

[a] Standard error of the means.
[b,c] Means in a row with different superscripts differ ($P<.01$).
[d,e] Means in a row with different superscripts differ ($P<.05$).

TABLE 3. INFLUENCE OF PEN TYPE AND COAT COLOR ON ANIMAL PERFORMANCE

Coat color	Black		Red		SE[a]
Pen type	Drylot	Confinement	Drylot	Confinement	
Steers	74	100	80	200	
Pens	2	2	2	2	
Daily gain, kg					
7/18 to 9/10	1.89[b]	1.42[c]	1.88[b]	1.36[c]	.03
9/10 to 10/21	1.00[d]	.69[e]	1.15[d]	.85[e]	.08
7/18 to 10/21	1.47[b]	1.12[c]	1.54[b]	1.16[c]	.31
Daily feed, kg	11.2[b]	8.9[c]	9.9[b]	8.9[c]	.44
Feed/Gain ratio	7.58	8.04	6.44	7.66	.29
Met energy, mcal/kg	2.71	2.71	3.01	2.76	.05
Dressing percent	64.8	63.5	61.7	63.5	.86
Percent choice	78.5	70.0	83.0	92.0	5.12

[a] Standard error of the mean.
[b,c] Means in a row with different superscripts differ ($P<.01$).
[d,e] Means in a row with different superscripts differ ($P<.05$).

TABLE 4. COMPARISON OF RESPIRATION RATES AND BODY SURFACE TEMPERATURES BETWEEN LOT TYPES ON 7/31/1982

	Time				
Treatment	0730	1030	1330	1630	1930
	Respiration rate, breaths per minute				
Drylot	74.1	100.1[a]	120.5	132.6	109.4
Confinement	76.6	127.9[b]	131.9	141.4	106.9
SE[a]	3.2	3.4	6.2	4.7	3.6
	Surface temperature, C				
Drylot	28.8[b]	40.8[b]	46.4[b]	45.3[a]	30.4
Confinement	34.4[c]	43.3[c]	39.2[c]	35.3[b]	29.2
SE[a]	1.1	1.2	1.2	.9	1.0

[a] Standard error of the mean.

[b,c] Means in a column with different superscripts differ (P<.05).

TABLE 5. COMPARISON OF RESPIRATION RATES BETWEEN COAT COLORS AND LOT TYPES ON 8/21/1982

Treatment	Coat color	Time 0800	1200	1600
		Respiration rate, breaths per minute		
Drylot	Black	60.4	132.2^{a}	128.3
Confinement	Black	57.9	144.6^{b}	126.1
Drylot	Red	57.6	131.3^{a}	129.3
Confinement	Red	82.6	146.2^{b}	138.7
SE[c]		7.4	2.1	7.6
Drylot	Overall	59.0	131.7^{a}	128.8
Confinement	Overall	70.3	145.4^{b}	132.4

[a,b] Means in a column and set with different superscripts differ ($P<.05$).

[c] Standard error of the mean.

TABLE 6. COMPARISON OF BODY SURFACE TEMPERATURES BETWEEN COAT COLORS AND LOT TYPES ON 8/21/1982

Treatment	Coat color	Time 0800	1200	1600
		Surface temperature, C		
Drylot	Black	29.0^{a}	47.6^{a}	43.3
Confinement	Black	33.3^{b}	44.6^{ab}	42.3
Drylot	Red	27.0^{a}	42.0^{bc}	42.0
Confinement	Red	32.7^{b}	39.0^{c}	42.4
SE[d]		.8	1.2	.9
Drylot	Overall	28.0^{a}	44.8	42.7
Confinement	Overall	33.0^{b}	41.8	42.3

[a,b,c] Means in a column and set with different superscripts differ (P<.05).

[d] Standard error of the mean.

TABLE 7. COMPARISON OF RESPIRATION RATES BETWEEN COAT COLORS AND LOT TYPES ON 9/04/1982

Treatment	Coat color	0730	1030	Time 1330	1630	1930
		Respiration rate, breaths per minute				
Drylot	Black	49.8	70.5^{a}	116.9^{a}	95.9^{a}	63.6^{a}
Confinement	Black	43.7	100.4^{b}	138.7^{b}	116.0^{b}	90.2^{b}
Drylot	Red	43.4	71.6^{a}	109.3^{a}	99.7^{a}	58.5^{a}
Confinement	Red	49.7	105.8^{b}	149.8^{b}	131.4^{b}	104.0^{b}
SE^{c}		2.8	7.3	5.5	9.1	5.5
Drylot		46.7	71.0^{a}	113.1^{a}	97.8^{a}	61.0^{a}
Confinement		46.6	103.1^{b}	144.3^{b}	123.7^{b}	97.1^{b}

[a,b] Means in a column with different superscripts differ ($P<.05$).
[c] Standard error of the mean.

TABLE 8. COMPARISON OF BODY SURFACE TEMPERATURES BETWEEN COAT COLORS AND LOT TYPES ON 9/04/1982

Treatment	Coat color	Time 0730	1030	1330	1630	1930
		Surface temperature, C				
Drylot	Black	28.4	40.9[a]	43.0	43.8	30.0
Confinement	Black	31.2	41.2[a]	44.4	40.5	30.1
Drylot	Red	27.9	38.0[b]	41.2	41.1	29.9
Confinement	Red	30.3	37.8[b]	42.7	39.7	30.3
SE[c]		1.4	1.0	1.1	1.0	.3
Drylot		28.2	39.4	42.1	42.4	30.0
Confinement		30.8	39.5	43.6	40.2	30.2

[a,b] Means in a column with different superscripts differ ($P<.05$).
[c] Standard error of the mean with 2 pens per treatment.

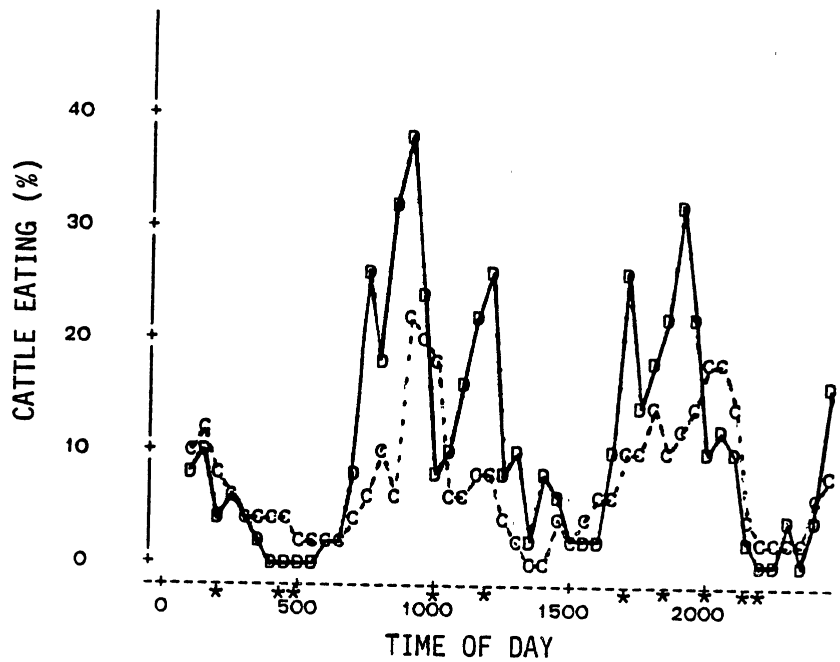

Figure 1. Percentage of Steers on Teardrop Floor(C) or in Dirt Floor(D) Pens Eating at Different Times

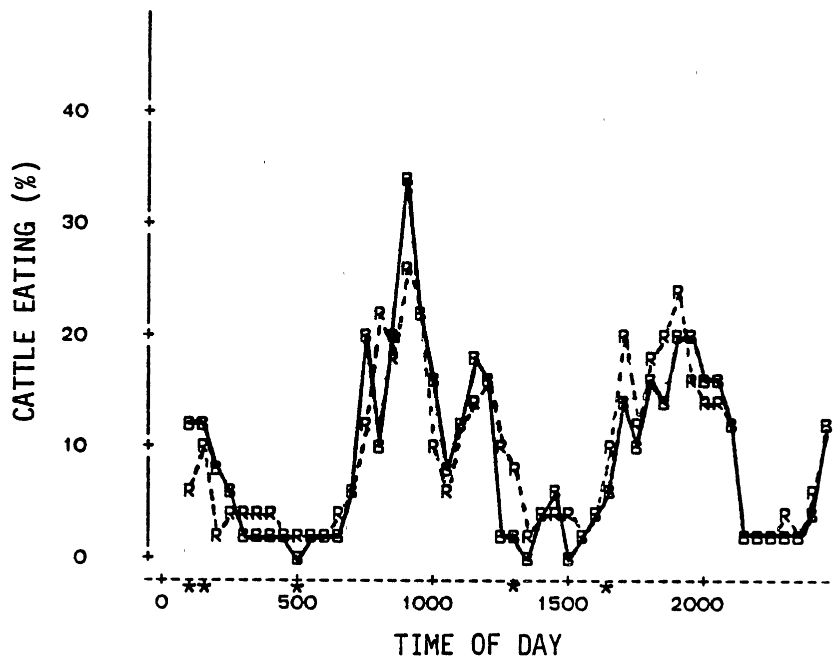

Figure 2. Percentage of Black(B) and Red(R) Steers Eating at Different Times

CHAPTER V

HEAT STRESS IN BROILER CHICKS

Abstract

The effects of supplemental dietary ascorbic acid, sodium bicarbonate and niacin on performance of broilers exposed to an elevated temperature were studied using 96 growing chicks. Arbor by Lancet chicks averaging 966 g were randomly allotted to either a chamber at 35 C or a thermoneutral environment and further subdivided into four dietary regimes--the basal corn-soybean meal diet containing 22% protein or the same diet with supplemental ascorbic acid (258 ppm), sodium bicarbonate (5000 ppm) or niacin (100 ppm added). Feed intake and weight gain were monitored as indicators of heat stress for a period of 2 weeks following one week of adjustment during which the temperature in the hot chamber was gradually raised to 35 C. Averaged across all diets, elevating the temperature to 35 C reduced intake by 23% and gain by 33%.

No benefit was observed for ascorbic acid or niacin supplementation in either the hot environment or for any of the three supplements in the thermoneutral environment. At 35 C,

sodium bicarbonate increased feed intake and weight gain, especially during the last week of the trial. control group, bicarbonate supplementation at 35 C increased feed intake by 12% and gain by 14% during the last week of the trial.

Introduction

Heat stress in poultry is a serious problem in many parts of the United States. In addition to death losses, feed intake and production can be severely reduced at elevated ambient temperatures. The objective of this study was to examine the effect of certain dietary supplements--ascorbic acid, niacin, and sodium bicarbonate--on feed intake and gain of broilers subjected to thermal heat stress.

Since research with these compounds under heat stress has been limited, choice of these compounds was based primarily upon physiological effects of heat. Supplemental dietary ascorbic acid has been shown to aid in maintaining body temperature of chicks in either a warm or cool environment (Thornton, 1962; Lyle and Moreng, 1968; Grimes and Moreng, 1965). Thornton (1961) demonstrated that when the environmental temperature was increased from 21 C to 31 C, the chick partially loses either the ability to synthesize ascorbic acid or to transport ascorbic acid in the blood. Depletion of adrenal ascorbic acid, and adrenal cholesterol together with increased plasma corticosteroids have been shown to be reliable indicators of stress in fowl (Siegel and Gross, 1965; Thaxton et al., 1968). Nathan et al. (1976) reported that during heat stress, leucocyte counts decrease while ascorbic acid concentrations in plasma and in leucocytes increase.

In laying hens, ascorbic acid has been shown to increase egg weight and egg shell thickness (Perek and Kendler, 1961). Body temperature response to ascorbic acid under heat stress conditions differs between layers and non-layers, suggesting that ascorbic acid may be metabolized differently (Lyle and Moreng, 1968). Growth response from chicks to supplemental ascorbic acid has been inconsistent, with some reports of beneficial effects (March and Biely, 1953; Combs et al., 1958) and one report of no benefit (Gogus and Griminger, 1959).

Niacin has been shown to cause vasodilation of the small vessels of the skin of the face and upper part of the trunk in humans (Spies et al., 1938). Concomitantly, skin temperature was increased and flushing, burning and itching of the skin was apparent. Later researchers found that niacin increased blood flow in the hand and forearm without changing blood pressure or pulse rate (Goldsmith and Cardill, 1969). Metabolic rate was not changed, so vasodilation was not compensatory to increased heat production, but rather was due to a local effect on the arterioles of the skin. Vasodilation due to niacin was found to be mediated by release of endogenous prostaglandin (Kaijser and Eklund, 1979). We postulated that increased blood flow to the body surface could speed heat dissipation to reduce heat stress.

When chicks are heat stressed to the point of rapid panting, they may suffer from respiratory alkalosis due to removal of carbon dioxide from the blood. Plasma pH is maintained in a narrow range of 7.36 to 7.44 (Trenkle et al., 1978). To compensate for a rise in blood pH, the renal tubules excrete a greater amount of sodium and bicarbonate in the urine which will reduce the buffering capacity of blood. Possibly, supplemental dietary sodium bicarbonate could replace this loss of bicarbonate and restore the buffer concentration of the blood.

Materials and Methods

Ninety six Arbor X Lancet broiler chicks (966 g) were randomly allotted to two temperatures--an environmental chamber at 35 C or a thermoneutral environment. Chicks in the thermoneutral treatment were housed in a well ventilated shed that exposed chicks to daily fluctuations in outdoor ambient air temperatures of 14 to 27 C with extremes of 8 and 32 C. The experiment was conducted from May 24 to June 14, 1983. Mean daily high temperature for the three weeks were 27, 25, and 28 with lows of 15, 12, and 16 C.

Birds in each environment were randomly allotted to four dietary regimes which were applied to the 16 pens, 8 at each temperature, with 6 chicks per pen and replicate pens per diet at each temperature. Diets consisted of a commercial chick grower mash (22% crude protein; 3.18 mcal ME/kg; table 1) without or with supplemental ascorbic acid (258 ppm), sodium bicarbonate (.5%) or niacin (27 vs 127 ppm).

Chicks were housed in stacked cages which contained eight compartments with two compartments at each level. Chicks had ad libitum access to the test diets and water from day 1. The trial lasted three weeks with the first week allowed as an adjustment period for the temperature in the environmental chamber to be gradually increased to 35 C. Chicks were weighed individually on days 7, 14, and 21 of the trial. Period 1 corresponds to the time period between days 7 and 14 while period 2 represents the period between days 14 and 21. All results were statistically analyzed for effects of environment, diet, and environment by diet interaction using the Analysis of Variance procedure (SAS, 1979).

Results and Discussion

Averaged across dietary treatments, chicks subjected to heat stress consumed 23% less ($P<.01$) feed and gained 33% less ($P<.01$) weight than chicks in the thermoneutral environment (table 2).

Effects of ascorbic acid and niacin on performance of the chicks were not apparent at either environmental temperature (tables 3 and 4). Feeding sodium bicarbonate to chicks, in contrast, tended to increase feed intake and weight gain of chicks at 35 C. Bicarbonate supplementation of chicks in the hot chamber increased feed consumption by 12% and gain by 15% for the total trial, and by 14% ($P<.05$) and 20% ($P<.05$), respectively, during the last week of the trial as compared to the controls.

The increased gain for chicks supplemented with sodium bicarbonate can be attributed to the increased feed intake. In turn, the response in feed intake may be partly ascribed to a location effect. Both groups of chicks on the sodium bicarbonate diet in the environmental chamber by random allocation were located in the bottom two cages of the battery. Previous experiments in this facility have shown a trend for chicks in the bottom cages to consume slightly more feed. The magnitude of the observed response cannot be attributed totally to the location effect in our opinion.

Explanations for the beneficial effect of sodium bicarbonate are not directly apparent. When chicks become heat stressed to the point of panting, their acid-base equilibrium is upset. In respiratory alkalosis, carbon dioxide is expired. The CO_2 is derived from carbonic acid (H_2CO_3) which is cleaved to water and CO_2. Carbonic acid is present at a 1:20 ratio with bicarbonate in the blood. As carbonic acid decreases, the concentration of bicarbonate decreases. Removal of this blood buffer permits the pH to rise.

A second possibility is that the response was due to sodium. Sodium is required by growing chicks at .15% of the diet (NRC, 1977), considerably below the .26% found in the diet in this experiment. The effect of heat stress on blood levels of sodium in fowl is uncertain. Other animals lose sodium or potassium through sweat. Acute heat stress decreased plasma levels of sodium in adult turkey hens in one study (Kohne and Jones, 1975a; 1975b), while in another study (Vo et al., 1978) heat stressed chicks maintained blood homeostasis of sodium as well as of other electrolytes. Edens (1976) intravenously injected avian saline (sodium chloride) prior to acute heat stress. Body temperature of injected broilers was significantly elevated with heat stress. This indicates that the positive response to sodium bicarbonate in our study was probably not due to supplemental sodium.

Blood pH, acid-base balance and electrolyte levels were not monitored in our experiment. To determine whether the response of heat stressed chicks to sodium bicarbonate was due to the sodium or to the bicarbonate and to determine what other dietary compounds might be useful to alleviate the effects of heat stress requires further experimentation.

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TABLE 1. CHICK DIET

Ingredient	Percentage
Corn grain, ground	54.85
Soybean meal	38.00
Alfalfa meal, dehydrated	3.00
Dicalcium phosphate	2.35
Calcium carbonate	.90
Vitamin mix	.40
Salt	.30
Trace mineral mix	.10
DL methionine	.10

TABLE 2. GAIN, FEED INTAKE AND EFFICIENCY OF CHICKS AT DIFFERENT TEMPERATURES[a]

Period	Feed intake, g		Daily gain, g		Feed/gain	
	1	2	1	2	1	2
Temperature						
Thermoneutral	143.0	142.7	60.0	51.9	2.38	2.75
35 C	103.2	116.9	38.5	36.0	2.69	3.27
SE[b]	2.7	1.1	1.3	.8	.05	.08

[a] Means in all columns differ ($P<.05$).
[b] Standard errors of the means.

TABLE 3. GAIN, FEED INTAKE AND EFFICIENCY OF CHICKS RECEIVING DIFFERENT SUPPLEMENTS AT THERMONEUTRAL TEMPERATURE

	Feed intake, g		Daily gain, g		Feed/gain	
Period	1	2	1	2	1	2
Supplement						
Control	141.6	144.5	59.1	53.5	2.40	2.70
Ascorbic acid	139.1	139.5	58.0	50.8	2.40	2.75
Bicarbonate	145.3	147.0	62.6	52.5	2.32	2.80
Niacin	145.9	139.8	60.4	51.0	2.42	2.75
SE[a]	5.5	2.2	2.6	1.6	.11	.16

[a] Standard errors of the means.

TABLE 4. GAIN, FEED INTAKE AND EFFICIENCY OF CHICKS RECEIVING DIFFERENT SUPPLEMENTS AT 35 C

	Feed intake, g		Daily gain, g		Feed/gain	
Period	1	2	1	2	1	2
Supplement						
Control	100.8	112.0[b]	39.2	32.7[b]	2.59	3.45
Ascorbic acid	100.2	111.4[b]	37.5	34.6[b]	2.69	3.24
Bicarbonate	111.8	127.4[a]	42.0	40.7[a]	2.67	3.13
Niacin	99.9	116.8[b]	35.3	36.0[ab]	2.82	3.25
SE[c]	5.5	2.2	2.6	1.6	.11	.16

[a,b] Means in a column with different superscripts differ ($P<.05$).
[c] Standard errors of the means.

CHAPTER VI

SUMMARY AND RECOMMENDATIONS

Findings from the first experiment indicate that for cattle in the southern Great Plains, intermittent sprinkling with water reduced summertime heat stress, especially when cattle were confined and exposed to solar radiation. This is in agreement with a number of other studies conducted at various locations throughout the US where sprinkling improved animal performance. The effectiveness of sprinkling cattle in dirt-lots requires further investigation. Although studies in some areas of the United States have shown sprinkling to be beneficial, effectiveness of sprinkling is dependent on climate and on the severity of muddy conditions created by sprinkling.

Red cattle when exposed to sunlight appeared to suffer slightly less than black cattle during periods of thermal stress based on respiration rates and body surface temperatures. This confirms work of Stewart and Brody (1954) who suggested that with exposure to solar radiation, body surface temperature was greater for cattle with darker than lighter coat colors. However, performance data does not currently justify sorting or selection for red cattle to feed in confinement pens and for black cattle to feed in dirt-lot pens. Based on respiration rates and body surface temperatures, confined white cattle were less affected by heat stress than black or red cattle. Respiration rates and body surface temperatures were higher for predominantly black than predominantly white Holstein steers in the same pen indicating that coat color influences surface temperature and respiration rate within a breed.

Space allowance for confined cattle (1.95 m^2 vs 2.42 m^2) did not alter performance. Earlier studies from Minnesota indicated that performance would increase as space allowance was increased by this amount. Further studies are needed to determine the optimum density for performance and for economics.

Diet modifications can be used to improve performance of heat stressed animals. Adding fat to the diet may reduce the heat increment and permit greater intake of net energy for gain. However, beneficial responses to added fat also may depend on the severity of heat stress and the relative input of different stressing factors. Whole corn rations may prove more desirable than cracked corn diets for feeding under heat stress conditions by reducing the heat of fermentation in the rumen.

In studies with heat stressed broiler chicks, growth response was not apparent with supplemental dietary ascorbic acid or niacin. Other researchers have reported beneficial response by heat-stressed chicks to supplemental ascorbic acid. Responses may be dependent on the dose level or periods of feeding relative to the heat stress. Adding sodium bicarbonate to the diet for heat stressed broiler chicks increased both feed intake and rate of gain. Although this response is believed to be associated with maintenance of acid-base balance of the blood under heat stress, more research is required to discern its influence on blood pH, partial pressure of CO_2 in the bloodstream, and other physiological parameters.

Further experimentation with these and other compounds is needed to find methods to alleviate heat stress in all livestock species.

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